Aerodynamic Measures of Normal Voice Production in Chinese Population in Hong Kong

SIN Wan Wai, Crystal

ABSTRACT

One of the usefulness of Aerodynamic measures is its non-invasive nature to investigate the relationship between phonation and airflow. Existing reports of aerodynamic measures are based primarily on the Western population. These normative data may not be applicable to population in Hong Kong because of the possible differences in physical functions and abilities between Western and Asian subjects.

The aims of this study, were first, to collect aerodynamic normative data for the Chinese population. The second aim was to investigate whether age and gender affected the aerodynamic measures in Chinese population.

Sixty subjects (30 males and 30 females) with normal voice in three age groups (21-30; 31-40; 41-50) were recruited for the study. The effect of gender was found in maximum sustained phonation time and inconsistently in mean airflow rates, peak air pressure and phonatory power. The effect of age was inconsistent and was only found in phonatory power.

INTRODUCTION

Normative data on laryngeal aerodynamic measures provide an objective set of quantitative data that may reflect the laryngeal function of an individual (Greene and Mathieson, 1989; Schutte, 1992). Since the use of aerodynamic measures to assess laryngeal function is noninvasive and relatively easy, therefore, such use is becoming more popular (Baken, 1987).

In the present study, the aim was to determine if age and gender differences exist in aerodynamic measures of Chinese speakers. There has been few studies reported in literature that have investigated these effects (Goozée, Murdoch, Theodoros and Thompson, 1998). Data on the ageing of the laryngeal function are primarily on white females and males from America and Europe (Kahane, 1987) and racial differences on the ageing of the larynx have not been studied specifically. Thus, there is a need to collect some normative data for the Chinese speakers as they may be physically different from the Westerners. These data would be useful for assessing Chinese patients with laryngeal dysfunctions. For diagnosis, the clinician can compare the values and observations obtained from the patient to normal responses.

It is known that the impact of ageing on voice production is related to the anatomic and physiologic changes that occur within the speech production mechanism (Kahane, 1987). Anatomical differences also account for the differences between male and female larynges, with difference in physical size being the predominant anatomical feature (Goozée et al., 1998). These age- and gender-related variations in the laryngeal structures, in turn, affect the laryngeal aerodynamics (Benjamin, 1988).

The primary aerodynamic measurements used in the assessment of voice function are air pressure and airflow (Dworkin and Meleca, 1996), and measures that are derived from them. These two aerodynamic properties are important in the process of phonation and they reflect a person's ability to use the respiratory system and vocal fold valving for voice production. The pressure of interest is the subglottal pressure immediately below the glottis and the flow is the airflow through the glottis (Lofqvist, 1992). In the current study, four tasks were administered to collect laryngeal aerodynamic data, namely, the maximum sustained phonation, most comfortable phonation, vocal intensity and vocal efficiency tasks. The latter two tasks were further divided into two parts which are to be explained in details in the method section.

Measurements of airflow rates provide data on the amount of airflow through the adducted vocal folds. The airflow patterns are useful for exploring the dynamics of speech production (Warren, 1982). In general, an airflow that is abnormally high implies a pathologic condition and suggests incomplete glottal closure and highly variable airflow rates during sustained phonation may also suggest imprecise laryngeal control (Miller and Daniloff, 1993). In the absence of severe ventilatory disorder, the measurement of the mean airflow a speaker uses during a sustained phonation has shown to be an effective clinical indicator of laryngeal dysfunction, both in organic and functional dysphonia (Orlikoff and Baken, 1993). Airflow testing is also useful for documenting the results of treatment for lesions such as nodules, a problem found frequently in professional voice users. (Spiegel, Sataloff, Cohn and Hawkshaw, year).

The use of sustained phonation may provide an index of phonatory-plus-respiratory efficiency. It can be assumed that the larger the vital capacity, the longer the phonation can be sustained. Hirano (1981) suggested maximum phonation time values, in general, smaller than ten seconds clinically should be considered to be abnormal. Patients with glottal incompetency often have low maximum phonation time as the air supply that powers the voice is quickly wasted. Vocal and respiratory fatigues are common complaints in these patients because most of them attempt to compensate for the leakage by adding a burden on the breathing mechanism.

Air pressure reflect the ability of the vocal folds to maintain adequate closure against the flow of air from the lungs. Patients with laryngeal pathologies, which cause either glottal incompetency and air wastage or airflow obstruction during phonation, often exhibit higher than normal subglottal pressure values. Again, this occurs as a result of increased respiratory efforts to compensate for such difficulties. Peak output of air pressure can be much higher due to the body being an excellent energy storage device, and it allows great surges of power to be withdrawn over short time intervals. The magnitude of air pressure beneath the vocal folds is important in producing vibration and determining the intensity of the sound.

Increasing the pressure of the air supply effectively increases the amount of air that is pushed through the glottis whenever it is open. In other words, this results in a greater vocal intensity. Typical loudness levels may be abnormal in various pathologies, for example, lack of vocal loudness is characteristic of paralysed cords, psychogenic disorders and anemia (Boone, 1983).

Glottal resistance is defined as the pressure across the glottis divided by the flow through the glottis (van den Berg, Zantema and Doornenbal, 1957). Patients with hyperfunctional vocal fold activity, such as those with adductor spasmodic dysphonia, plica ventricularis, and generalised muscle tension dysphonia, usually exhibit significantly higher glottal resistance as a consequence of increased intraglottal compression forces (Dworkin and Meleca, 1996). Those, however, with vocal fold paralysed struggle with very low glottal resistance.

Phonatory power is a derived measure and is calculated as the product of estimated suglottal pressure multipled by the phonatory flow rate (Tanaka and Gould, 1983; Schutte, 1992).

Phonatory efficiency can be calculated from measurements of pressure, flow, and the sound pressure in the speech signal (Lofqvist, 1992). The efficiency value is the ratio of output and input and the input is the work done by the respiratory system during sound production.

Although the increasing popularity of using aerodynamic measures to test laryngeal functions is being recognised, it must be noted that these measurements can show variability between voices and even in voices judged to be normal. In Schutte's (1986) study, for example, aerodynamic measurements of 24 male and 21 female normal voices were collected and the spread in the data collected made it impossible to provide well delimited 'normal' values for air pressure and airflow. The reason for this is simply that voices differ. Therefore, it may be of little value to relate and compare measurements on a given voice to average values for a group of normal voices. However, meaningful comparisons may be made within a given voice which makes it possible to follow changes within a voice over time, for example, as a function of therapy or surgery. Nonetheless, collecting normative data will give us some references and ideas regarding normal and abnormal laryngeal functions. However, careful use and interpretation of data is needed, since what we perceive as 'abnormal voice' may stem from a variety of causes and etiology. Thorough assessment including using various instruments will certainly be needed. Unless these etiologies are determined, effective and appropriate treatment cannot be provided.

METHODS

Subjects

The subject group consisted of 60 native Cantonese adults with normal voice (30 males and 30 females) between the age of 21 and 50 years. There were three age groups (21-30; 31-40; 41-50) in each gender. Each subject was judged perceptually by the investigator and another student speech therapist as having normal voice quality.

Procedures

Kay Elemetrics' Aerophone II was used. The aerodynamic recording was conducted in a sound-treated booth, with each subject seated comfortably in an upright position. This body posture is important as it contributes to efficiency of respiration (Seikel, King and Drumright, 1997). The whole assessment took approximately 30 minutes in duration.

A facemask connected to the transducer of the Aerophone II was used to measure airflow and each subject was required to hold it firmly over the face to ensure an adequate seal around the face. A 6.0-cm-long polyethylene tube with an internal diameter of 2.5mm was positioned centrally over the top of the subject's tongue, together with the facemask, in one of the tasks to collect air pressure.

Each task was demonstrated by the investigator prior to the recordings of the subject's performance, and the subject would then be given time to practise the task first without using the facemask. The subject was required to conduct each task five times, and the average performance was calculated in the data analysis stage.

Task 1: Maximum Sustained Phonation

Each subject was required to take a deep breath before phonation, then, to sustain the vowel /a/ for as long as possible with his/her most comfortable pitch and loudness levels. The same procedure was repeated for the vowels /i/ and /u/. During phonation, the subject's maximum phonation time and mean airflow rates were measured.

Task 2: Most Comfortable Phonation

Each subject was reminded that there was no need to take a deep breath before phonation in the remaining tasks. This task required the subject to phonate /a/ for approximately six seconds at his/her most comfortable pitch and loudness levels and the subject's sound pressure level and mean airflow rates were measured.

Task 3: Vocal Intensity (Minimum and Maximum Sound Pressure Levels)

In the minimum sound pressure level part, each subject was asked to phonate /a/ and to sustain it for approximately six seconds with his/her most comfortable pitch and loudness levels then to reduce the loudness to as soft as possible. The same procedure applied to the maximum sound pressure level part. Instead of gradually decreasing vocal intensity, the subject was required to increase his/her loudness to as loud as possible. From these, the subject's minimum and maximum sound pressure levels and mean airflow rates were measured.

Task 4: Vocal Efficiency (Repetition of /pi/ and Running Speech /pa pa ta pɔ/

In the repetition of the consonant-vowel sequence, the subject was required to phonate the vowel /i/, then followed by seven productions of /pi/ in one breath at a rate of approximately three syllables per second. In running speech, the subject was required to produce /pa pa ta pɔ/ with his/her most comfortable pitch and loudness levels. Six aerodynamic parameters were measured or calculated during this task, including mean airflow rate, mean air pressure, peak air pressure, phonatory power, phonatory efficiency and phonatory resistance.

DATA ANALYSIS

In analysing the data obtained in tasks 1 to 3, appropriate segments of the signals were selected for calculation. To do this, a cursor was placed at the very beginning of the waveform of the sound pressure level signal (represented by the start of the rising slope), whereas another cursor was placed at the end of the vowel (marked by the end of the decreasing slope).

In the repetition of /pi/ (task 4), only five productions of /pi/ were used for analysis (from the end of the third peak to the end of the eighth peak of the waveform). In the running speech /papatapɔ/ (task 4), the whole sentence was included for analysis (from the beginning of the first peak to the end of the fourth peak of the waveforms).

For statistical analysis, SPSS 10.0 was used. The effects of age and gender of these measures were examined using analysis of variance.

RESULTS

Task 1: Maximum Sustained Phonation

The mean and the overall mean values of maximum sustained phonation time and mean airflow rates in the productions of /a/, /i/ and /u/ are reported in tables 1a and 1b, respectively.

Results revealed significant main effects for gender in maximum sustained phonation time and in mean airflow rates in the productions of all three vowels. Male subjects were found to be able to sustain phonation for significantly longer and to produce significantly higher mean airflow rate values than the females. (See table 2.) No significant main effects for age and no interaction effects of gender by age were found.

TABLE 1. Means and standard deviations of maximum sustained phonation time and airflow rate (maximum sustained phonation task)

a) Maximum sustained phonation time

Vowel	Parameter	Gender		Age group (years) 21-30	31-40	41-50	Overall
/a/	Maximum	Male	mean	20.45	19.24	20.92	20.20
	sustained		SD	6.89	7.19	7.23	6.89
	phonation	Female	mean	15.18	15.92	16.75	15.95
	time (sec)		SD	4.12	3.65	5.63	4.44
/i/	Maximum	Male	mean	21.65	17.95	24.19	21.26
	sustained		SD	9.98	5.38	8.09	8.19
	phonation	Female	mean	15.46	16.84	16.44	16.25
	time (sec)		SD	5.02	4.06	5.45	4.74
/u/	Maximum	Male	mean	23.50	17.91	20.38	20.59
	sustained		SD	8.78	6.80	4.28	7.03
	phonation	Female	mean	14.64	15.50	15.98	15.38
	time (sec)		SD	3.20	3.91	4.19	3.70

SD standard deviation

b) Airflow rate

				Age group (years)			
Vowel	Parameter	Gender		21-30	31-40	41-50	Overall
/a/	Mean	Male	mean	0.16	0.11	0.12	0.13
	airflow rate		SD	0.06	0.58	0.06	0.06
	(Litres/sec)	Female	mean	0.08	0.10	0.09	0.09
			SD	0.05	0.04	0.04	0.04
/i/	Mean	Male	mean	0.17	0.13	0.13	0.14
	airflow rate		SD	0.08	0.04	0.04	0.06
	(Litres/sec)	Female	mean	0.08	0.10	0.08	0.09
			SD	0.04	0.02	0.04	0.03
/u/	Mean	Male	mean	0.16	0.16	0.14	0.15
	airflow rate		SD	0.08	0.60	0.05	0.07
	(Litres/sec)	Female	mean	0.10	0.14	0.09	0.11
			SD	0.04	0.11	0.04	0.07

SD standard deviation

TABLE 2. ANOVA results for each vocal measure in maximum sustained phonation task

		Sustained phonation time		Mean phonatory flow rate	
		F (1,2)	p	F (1,2)	p
/a/	Gender	7.63	0.008*	7.83	0.007*
	Age	0.25	0.78	0.79	0.46
	Gender x Age	0.13	0.88	2.31	0.11
/i/	Gender	8.53	0.005*	19.48	0.000*
	Age	0.98	0.38	1.17	0.32
	Gender x Age	1.36	0.27	1.17	0.32
/u/	Gender	13.26	0.001*	5.25	0.026*
	Age	0.93	0.40	1.37	0.26
	Gender x Age	1.78	0.18	0.65	0.53

* significant at 0.05 level

Task 2: Most Comfortable Phonation

The mean and the overall mean values of sound pressure level and mean airflow rates during the most comfortable phonation are reported in table 3. For sound pressure level, none of the ANOVA shows any significant results.

Results revealed a significant main effect for gender in mean airflow rates during the most comfortable phonation, with male subjects producing significantly higher mean airflow rate values. (See table 4.) No significant main effects for age and no interaction effects of gender by age were found.

TABLE 3. Means and standard deviations of each vocal measure (most comfortable phonation task)

			Age group (years)			
Parameter	Gender		21-30	31-40	41-50	Overall
Mean sound	Male	mean	74.54	73.10	72.46	73.37
pressure level		SD	7.02	5.33	8.46	6.86
(dB)	Female	mean	69.56	73.12	75.58	72.75
		SD	4.31	6.38	8.05	6.69
Mean airflow	Male	mean	0.14	0.11	0.13	0.13
rate		SD	0.09	0.05	0.07	0.07
(Litres/sec)	Female	mean	0.09	0.11	0.09	0.10
		SD	0.04	0.04	0.04	0.04

SD standard deviation

TABLE 4. ANOVA results for each vocal measure in most comfortable phonation task

	Mean sound pressure level		Mean airflow rate	
	F (1,2)	p	F (1,2)	P
Gender	0.12	0.73	4.77	0.033*
Age	0.43	0.66	0.08	0.93
Gender x Age	1.35	0.27	1.35	0.27

* significant at 0.05 level

Task 3: Vocal Intensity

Part I: Minimum Sound Pressure Level

The mean and the overall mean values of minimum sound pressure level and mean airflow rates during phonation are reported in table 5. For both parameters, none of the ANOVA shows any significant results. (See table 6.)

TABLE 5. Means and standard deviations of each vocal measure (minimum sound pressure level)

			Age group (years)			
Parameter	Gender		21-30	31-40	41-50	Overall
Mean minimum	Male	mean	64.36	64.44	65.54	64.78
sound pressure		SD	5.48	5.38	4.60	5.02
level (dB)	Female	mean	63.71	65.24	66.34	65.10
		SD	4.08	4.28	5.28	4.55
Mean airflow	Male	mean	0.11	0.10	0.13	0.11
rate (Litres/sec)		SD	0.08	0.07	0.09	0.08
	Female	mean	0.08	0.12	0.09	0.10
		SD	0.04	0.06	0.06	0.06

SD standard deviation

TABLE 6. ANOVA results for each vocal measure in minimum sound pressure level task

	Mean sound pressure level		Mean airflow rate	
	F (1,2)	p	F (1,2)	p
Gender	0.06	0.80	0.94	0.34
Age	0.77	0.47	0.59	0.56
Gender x Age	0.15	0.86	0.98	0.38

Part II: Maximum Sound Pressure Level

The mean and the overall mean values of maximum sound pressure level and mean airflow rates are reported in table 7. For sound pressure level, none of the ANOVA shows any significant results.

Results revealed a significant main effect for gender in mean airflow rate, with male subjects producing significantly higher mean airflow rate values. (See table 8.) No significant main effect for age and no interaction effect of gender by age were found.

TABLE 7. Means and standard deviations of each vocal measure (maximum sound pressure level)

			Age group (years)			
Parameter	Gender		21-30	31-40	41-50	Overall
Mean maximum	Male	mean	81.86	80.24	77.58	79.89
sound pressure		SD	7.55	3.01	6.32	6.01
level (dB)	Female	mean	80.08	76.54	79.48	78.70
		SD	5.95	6.47	7.40	6.59
Mean airflow	Male	mean	0.18	0.16	0.19	0.18
rate (Litres/sec)		SD	0.08	0.09	0.10	0.09
	Female	mean	0.09	0.11	0.09	0.10
		SD	0.04	0.03	0.04	0.04

SD standard deviation

TABLE 8. ANOVA results for each vocal measure in maximum sound pressure level task

	Mean sound pressure level		Mean airflow rate	
	F (1,2)	p	F (1,2)	P
Gender	0.54	0.47	19.13	0.000*
Age	1.06	0.35	0.02	0.98
Gender x Age	1.02	0.37	0.75	0.48

* significant at 0.05 level

Task 4: Vocal Efficiency

Part I: Repetition of Consonant-Vowel Sequence

The mean and the overall mean values of mean airflow rate, peak and mean air pressure, and phonatory power, resistance and efficiency are reported in table 9.

Results revealed significant main effects for gender in peak air pressure and phonatory power, with male subjects producing higher values than the females. (See table 10.) For other parameters, none of the ANOVA shows any significant results.

TABLE 9. Means and standard deviations of each vocal measure (vocal efficiency task)

			Age group (years)			
Parameter	Gender		21-30	31-40	41-50	Overall
Mean airflow rate (Litres/sec)	Male	No. of cases	10	9	10	29
		mean	0.17	0.20	0.27	0.21
		SD	0.15	0.08	0.16	0.14
	Female	No. of cases	9	9	10	28
		mean	0.09	0.19	0.17	0.15
		SD	0.05	0.14	0.18	0.14
Peak air pressure (cmH_2O)	Male	No. of cases	7	6	4	17
		mean	9.67	10.42	10.75	10.19
		SD	3.59	2.71	3.75	3.16
	Female	No. of cases	8	8	10	26
		mean	9.46	7.34	7.24	7.95
		SD	2.27	3.83	3.11	3.17
Mean air pressure (cmH_2O)	Male	No. of cases	10	9	10	29
		mean	2.49	2.51	1.85	2.28
		SD	0.98	2.14	1.17	1.47
	Female	No. of cases	10	10	10	30
		mean	3.10	2.23	1.91	2.41
		SD	1.88	1.84	0.92	1.63

TABLE 9. Means and standard deviations of each vocal measure (vocal efficiency task)

Phonatory	Male	No. of cases	7	6	4	17
power		mean	0.16	0.19	0.38	0.22
(Watts)	Female	SD	0.15	0.05	0.24	0.17
		No. of cases	7	7	10	24
		mean	0.10	0.13	0.15	0.13
		SD	0.08	0.09	0.19	0.13
Phonatory	Male	No. of cases	7	6	4	17
resistance		mean	163.45	73.56	76.50	111.26
(Ns/m^5)		SD	190.19	61.05	82.55	134.29
	Female	No. of cases	N= 8	N= 7	N= 10	N= 25
		mean	418.61	56.09	174.70	219.54
		SD	732.44	40.02	270.49	454.03
Phonatory	Male	No. of cases	7	6	4	17
efficiency		mean	70.53	28.93	71.30	56.03
(ppm)		SD	32.02	17.43	50.97	37.31
	Female	No. of cases	8	7	10	25
		mean	251.86	46.21	122.46	142.52
		SD	606.34	56.89	140.08	349.65

ppm = parts per million

Ns/m^5= Newton seconds/metres

SD standard deviation

TABLE 10. ANOVA results for each vocal measure in repetition of consonant-vowel sequence of vocal efficiency task

	Mean airflow rate		Mean air pressure		Peak air pressure		Phonatory power		Phonatory efficiency		Phonatory resistance	
	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p
Gender	3.17	0.08	0.10	0.75	4.93	0.033*	6.31	0.017*	0.87	0.36	0.94	0.34
Age	2.08	0.14	1.77	0.18	0.18	0.83	2.98	0.06	0.69	0.51	1.48	0.24
Gender x Age	0.42	0.66	0.42	0.66	1.08	0.35	1.34	0.28	0.34	0.71	0.50	0.61

* significant at 0.05 level

Part II: Running Speech

The mean and the overall mean values of mean airflow rate, peak and mean air pressure, and phonatory power, resistance and efficiency are reported in table 11. A post-hoc test was conducted and it was found that the phonatory power values were significantly different between the age groups of 21-30 and 41-50, and between 31-40 and 41-50 (See table 13.)

Results revealed significant main effects for age in phonatory power, with male subjects producing higher values than the females. (See table 12.) For other parameters, none of the ANOVA shows any significant results.

TABLE 11. Means and standard deviations of each vocal measure (sentence task)

			Age group (years)			
Parameter	Gender		21-30	31-40	41-50	Overall
Mean	Male	No. of cases	10	10	10	30
airflow rate		mean	0.49	0.12	0.45	0.35
(Litres/sec)		SD	1.18	0.06	0.91	0.84
	Female	No. of cases	10	10	10	30
		mean	0.06	0.09	0.12	0.09
		SD	0.03	0.06	0.10	0.07
Peak air	Male	No. of cases	4	6	4	14
pressure		mean	6.48	6.86	8.11	7.11
(cmH_2O)		SD	2.67	3.50	4.51	3.39
	Female	No. of cases	6	7	5	18
		mean	7.46	6.08	6.28	6.59
		SD	2.05	3.13	1.15	2.33

TABLE 11. Means and standard deviations of each vocal measure (sentence task)

Mean air	Male	No. of cases	10	8	10	28
pressure		mean	1.53	2.22	1.83	1.83
(cmH_2O)		SD	0.61	1.59	0.83	1.04
		No. of cases	10	10	10	30
	Female	mean	1.54	1.36	1.42	1.44
		SD	0.32	0.56	0.53	0.48
Phonatory	Male	No. of cases	4	5	6	15
power		mean	0.07	0.08	0.20	0.13
(Watts)	Female	SD	0.33	0.02	0.13	0.10
		No. of cases	6	8	5	19
		mean	0.05	0.05	0.10	0.07
		SD	0.03	0.03	0.09	0.05
Phonatory	Male	No. of cases	4	5	6	15
resistance		mean	63.81	87.74	45.15	64.32
(Ns/m^5)		SD	19.46	61.54	23.98	41.50
	Female	No. of cases	6	8	5	19
		mean	140.55	169.16	90.14	139.33
		SD	105.80	201.82	105.95	150.04

TABLE 11. Means and standard deviations of each vocal measure (sentence task)

Phonatory	Male	No. of cases	4	5	6	15
efficiency		mean	456.18	371.61	122.22	294.41
(ppm)		SD	262.71	438.65	161.20	318.36
	Female	No. of cases	6	8	5	19
		mean	253.33	2388.33	764.32	1286.75
		SD	198.47	5445.50	994.49	3568.44

ppm = parts per million

Ns/m^5= Newton seconds/metres

SD standard deviation

TABLE 12. ANOVA results for each vocal measure in sentence production of vocal efficiency task

	Mean airflow rate		Mean air pressure		Peak air pressure		Phonatory power		Phonatory efficiency		Phonatory resistance	
	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p	F (1,2)	p
Gender	2.81	0.10	3.96	0.05	0.26	0.62	4.03	0.05	0.72	0.41	2.57	0.12
Age	0.53	0.59	0.48	0.62	0.17	0.84	5.99	0.007*	0.49	0.62	0.74	0.49
Gender x Age	0.58	0.57	1.39	0.26	0.54	0.59	1.02	0.38	0.46	0.64	0.08	0.93

* significant at 0.05 level

TABLE 13. Post-hoc (Bonferroni test) results for phonatory power in sentence task

Age of subjects		p
21-30	31-40	1.00
	41-50	0.009*
31-40	21-30	1.00
	41-50	0.008*
41-50	21-30	0.009*
	31-40	0.008*

* significant at 0.05 level

DISCUSSION

In the present study, preliminary normative data have been collected. Using these data that show the aerodynamic characteristics of normal voice production in Chinese speakers, the clinician can describe a patient's laryngeal function in terms of how close it is to the normative data.

From these data, the effects of age and gender on laryngeal aerodynamics were examined. To summarise, the effect of age was only found in phonatory power during the repetition of consonant-vowel sequence and not in the other measures. Since the present study investigated only three age groups (ranging from 21 to 50 years), compared with the study by Goozée et al. in which subjects up to the age of 80 years old were included, therefore, it may well be that the anatomical and physiological changes due to the ageing process might not have emerged at this early age yet (Melcon, Hoit and Hixon, 1989).

The effect of gender was found in various aerodynamic parameters of various tasks, which are summarised in table 14.

TABLE 14. The effect of gender in the six aerodynamic parameters measured in the four vocal tasks

Aerodynamic parameter	Task 1 MSP	Task2 MCP	Task3 Max SPL	Task3 Min SPL	Task4 Series of /pi/	Task4 Sentence
Mean airflow rates	✔	✔	✔	✕	✕	✕
Mean air pressure	N/A	N/A	N/A	N/A	✕	✕
Peak air pressure	N/A	N/A	N/A	N/A	✔	✕
Phonatory power	N/A	N/A	N/A	N/A	✔	✕
Phonatory resistance	N/A	N/A	N/A	N/A	✕	✕
Phonatory efficiency	N/A	N/A	N/A	N/A	✕	✕

✔ effect of gender

✕ no effect of gender

Maximum Sustained Phonation Time

Vital capacity decreases as age increases, therefore, one would consider that the younger subjects would be able to sustain phonation for long duration than the elderly subjects. However, this assumption did not apply in the finding of the current study, with the possible factor that the age range covered did not reflect such ageing process, although some investigators found that reduction in laryngeal valving may affect phonation time and loudness which contribute to the finding of reduced phonation time in older males (Ptacek, Maloney and Jackson, 1966).

Gender differences, however, were found. The results of the current study indicated that the male speakers could sustain phonation for a significantly longer duration than the female speakers. This finding is consistent with the results of a number of previous studies (e.g. Ptacek and Sander, 1963; Sawashima, 1966; Hirano, Koike and von Leden, 1968; Shigemori, 1977). It appears that such measure is greater for males than females, which can be explained by the structural differences that exist between them. The vital capacity in adult males (4800cc) is greater, compared with females (3200cc) (Seikel et al., 1997).

Airflow Rates

In the present study, airflow rates were measured in all tasks and the male subjects were found to produce significantly greater phonatory flow rates than the females during the maximum sustained phonation and the most comfortable phonation tasks, and during the maximum sound pressure level part of the vocal intensity task. This finding is consistent with a number of investigations (e.g. Holmberg, Hillman and Perkell, 1988; Higgins and Saxman, 1991; Wilson and Leeper, 1992; Holmes, Leeper and Nicholson, 1994).

Most of these investigators have hypothesised that the anatomical and physiological respiratory and laryngeal differences in males and females probably account for the higher airflow rates produced by males. Such differences include the slightly larger physical size of the male glottis, the larger male vocal tract orifice areas, the larger respiratory volume and greater lung elasticity of males (Kahane, 1983a; Holmberg et al., 1988; Wilson and Leeper, 1992; Stathopoulos and Sapienza, 1993; Holmes et al., 1994).

The effect of gender was, however, not apparent in phonation at minimum sound pressure level, repetition of consonant-vowel sequence and sentence production. Possible factor to account for such finding may involve the subjects making laryngeal and respiratory behavioural adjustments in performing these tasks.

Vocal Intensities

Phonatory sound pressure levels were measured during the subject's most comfortable phonation, and during phonation at his/her maximum and minimum sound pressure levels. No age differences were found. These findings did not agree with those previously reported, for example, Morris and Brown (1994). In their study on age differences in speech intensity among adult females, older women produced lower maximum intensities and higher minimum intensities than the younger women. In other words, older women demonstrate narrower dynamic range. Respiratory changes and changes in the larynx that occur with age were suggested to be the factors in such findings.

Only a limited number of studies have investigated the effects of gender on phonatory sound pressure level. Holmes et al. (1994) reported that the male subjects produced significantly higher sound pressure levels in comparison to the females in a vocal efficiency task. Results in the current study indicated no significant gender differences.

Air pressure

Mean air pressure was not found to be significantly different in age and in gender during repetition of consonant-vowel sequence and sentence production tasks. However, the effect of gender was found in peak air pressure during the repetition of consonant-vowel sequence, with the values produced by males being higher than females.

Phonatory power, resistance and efficiency

The effect of age was found in phonatory power during sentence production. The effect of gender was found in phonatory power during the repetition of consonant-vowel sequence, with the values produced by males being higher than the females. This finding is different from the study conducted by Goozée et al. (1998) where the phonatory power values obtained by the male subjects were similar to those obtained by the female subjects. Phonatory resistance, obtained by the male and female subjects in the present study was not found to differ significantly, both in consonant-vowel sequence and sentence tasks. Although this finding is consistent with the findings of Stathopoulos and Sapienza (1993) and Goozée et al. (1998), it is in opposition to the findings of a number of previous investigations, including Holmes et al. (1994) and Netsell, Lotz, DuChane and Barlow (1991) where females were found to have larger glottal resistances than males, presumably because of their smaller larynges.

The effect of age and of gender were not found in vocal efficiency index. These findings are consistent with the findings of Holmberg et al. (1988) and Goozee et al. (1997). They are in opposition, however, with the results obtained by Schutte (1981) who reported that females have higher vocal efficiency values than males. The discrepancies of these findings may be explained on the basis of differences in methodology. In Schutte's (1981) study, the subjects were required to phonate at a target intensity level, whereas in the current study, intensity was not controlled and the subjects were asked to phonate using their most comfortable loudness. As Schutte (1981) suggested, phonatory efficiency has been found to be proportional to intensity because of an increase in vocal fold tension and shortening of the glottal open time, therefore, the methodology used in this study might allow high intersubject variability. Standardisation of test intensity levels may, therefore, be important.

Results in investigations of aerodynamics of voice production reported in literature appear to be controversial. Taking the measurement of airflow as an example, some investigators, for example, Holmes et al. (1994), reported that the male subjects demonstrated significantly greater airflow rates in comparison to females where other investigators reported differently; for example, Goozée et al. (1998) found that the male and female subjects produced similar airflow rates to the females.

Possible factors contributing to such controversy may be demonstrated by the differences in methodology, including the use of instrumentation, the designs of tasks (the requirements and procedures involved), the number of subjects used, and the age ranges being explored.

The Use of Instrumentation

The techniques of pneumotachographs to collect phonatory flow rate measures were used in the majority of previous investigations (Stathopoulos and Sapienza, 1993), including Holmes et al.'s (1994) study, as opposed to the Aerophone II that was used in the study conducted by Goozée et al. (1998) and in the current study.

Task Designs

In Goozée et al.'s (1998) study, the male subjects were found to produce similar phonatory flow rates to the females in the vocal efficiency and running speech tasks. Such findings are consistent with results reported by Stathopoulos and Sapienza (1993) who used the vocal efficiency task. In Holmes et al.'s (1994) study, where males were found to produce higher flow values than did females, different procedures were used; airflow rates were collected across four different levels of sound pressure. Different tasks and procedures used in these investigations may have contributed to a higher intersubject variability which may have prevented significant gender differences from being detected. The impact of age and gender differences on speech production mechanism may vary with the nature of the vocal task.

Number of Subjects and Age Ranges

Twenty subjects were recruited in Holmes et al.'s (1994) study, compared with 109 subjects in Goozée et al. (1998) study, giving quite a large difference in the sample sizes. The subjects' ages ranged from 55 to 75 in Holmes et al.'s (1994) study while from 20 to 50 in the present study.

Based on these dissimilarities in methodology, it is perplexing for comparisons of data obtained from different investigations. Thus, the author believes that it would be beneficial to standardise the procedures and methodology used in obtaining the data in order to allow for comparisons, otherwise, the validity of the results may be compromised.

In using these normative data as references, careful interpretation is important. As suggested by Schutte (1992), clinicians seem to overestimate, for example, the diagnostic value of airflow measurements. The diagnostic procedures apparently fail because the maximum phonation time can be altered by many factors, including age, sex, oxygen tension of the blood, training, voice onset, pitch loudness level, and emotions. In vocal efficiency, an increase of such index does not necessarily mean healthier phonation patterns (Schutte, 1992) or well-functioning larynx, since short-term gains in energy conversion may easily be obtained at the price of eventual injury or disorder.

Therefore, unless all possible factors are taken into considerations, the value of the aerodynamic measures may not be useful or reliable to be used as a diagnostic guide since inter-individual as well as intra-individual differences are too large.

LIMITATIONS AND FUTURE RESEARCH

The normative data collected in the present study are useful for our reference and understanding of normal voice. Yet, the data collected are of a very preliminary nature as only a small sample size was used. Further research on other aerodynamic parameters covering larger age ranges and possibly larger sample size will be warranted.

Tasks may be further developed or modified to resemble our daily vocal use. For example, we rarely breathe in maximally and then speak by using all the entire vital capacity. In other words, our function for speech rarely reaches a maximum output level and stress. Speaking tasks that result in minimal normal variability while still approximating the dynamics of normal speech production would be the most desirable from a clinical perspective.

Peak airflow varies as a function of speech intensity. It is, therefore, of some importance that speech intensity be controlled during testing. Stathopoulos (1985) has shown that simply instructing the subject to maintain a comfortable speech loudness is just as effective in controlling vocal variability.

Some of the data collected for the parameters measured in the repetition of consonant-vowel sequence and sentence production tasks could not be calculated automatically by the computer as the data might not fulfil the set requirements. Therefore, these data were disregarded and excluded from the study. As a consequence, the number of subjects was not all identical in each group. This might decrease the level of reliability.

Importantly, a clinician must be aware that aerodynamic measures are not very useful for determining the cause of the voice disorder; the purpose is to measure the degree of dysfunction. No single test can measure total vocal function, we must test several different aspects to get a composite picture of how the laryngeal and respiratory system are working together to produce voice. Thus, aerodynamics provide information on one part of the total picture only.

To summarise, research conducted so far may not be able to reliably differentiate pathological groups since the literature on normal speakers across age levels is often sparse and profiles of speakers with specific dysphonias are limited to a few pathologies or to a small number of test results. Nonetheless, they are undoubtedly useful to help differentiate people with normal from abnormal laryngeal functions.

ACKNOWLEDGEMENTS

Thanks are given to Dr. Edwin Yiu for his continuous support and patience throughout the study, and to Miss Estella Ma and Miss Nicole Li for their assistance in using the instruments.

Sincere gratitude are expressed to Miss Yu Shui Fung, Miss Irene Lam and Mr. Tecth Lam for their enormous help and time devoted in subject recruitments, and to all the subjects involved in this study.

REFERENCES

Baken, R. J. (1987). Clinical measurement of speech and voice. Boston, MA: College-Hill Press.

Benjamin, B. J. (1988). Changes in speech production and linguistic behaviours with ageing. In B. B. Shadden (Ed.), Communication behaviour and ageing. A sourcebook for clinicians (pp. 162-181). Baltimore: Willimas and Wilkins.

Boone, D. R. (1983). The voice and voice therapy. Englewood Cliffs, NJ: Prentice-Hall.

Dworkin J. P., & Meleca R. J. (1996). Vocal pathologies: diagnosis, treatment, and case studies. San Diego, CA: Singular Publishing Group, Inc.

Goozée, J., Murdoch, B., Theodoros, D., & Thompson, E. (1998). The effects of age and gender on laryngeal aerodynamics. International Journal of Language and Communication Disorders, 33(2), 221-238.

Greene, M. C. L., & Mathieson, L. (1989). The voice and its disorders. London: Whurr Publishers.

Higgins, M., & Saxman, J. (1991). A comparison of selected phonatory behaviours of healthy aged and young adults. Journal of Speech and Hearing Research, 34, 1000-1010.

Hirano, M. (1981). Clinical examination of voice. New York: Springer-Verlag.

Hirano, M., Koike, Y., & von Leden, H. (1968). Maximum phonation time and air usage during phonation. Clinical study. Folia Phoniatrica, 20, 185-201.

Holmberg, E., Hillman, R., & Perkell, J. (1988). Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal and loud voice. Journal of the Acoustical Society of America, 84, 511-529.

Holmes, L., Leeper, H., & Nicholson, I. (1994). Laryngeal airway resistance of older men and women as a function of vocal sound pressure level. Journal of Speech and Hearing Research, 37, 789-799.

Kahane, J. (1983a). Postnatal development and ageing of the human larynx. Seminars in Speech and Language, 4, 189-203.

Kahane, J. (1987). Connective tissue changes in the larynx and their effects on voice. Journal of Voice, 1(1), 27-30.

Lofqvist, A. (1992). Aerodynamic measurements of vocal function. In A. Blitzer, M. F. Brin, C. T. Sasaki, S. Fahn, & K. S. Harris (Eds.), Neurologic disorders of the larynx (pp. 98-107). New York: Thieme Medical Publishers, Inc.

Melcon, M., Hoit, J., & Hixon, T. (1989). Age and laryngeal airway resistance during vowel production. Journal of Speech and Hearing Research, 54, 282-286.

Miller, C. J. & Daniloff, R. (1993). Airflow measurements: Theory and utility of findings. Journal of Voice, 7(1), 38-46.

Morris, R., & Brown, W. (1994). Age-related differences in speech intensity among adult females. Folia Phoniatrica Logopedica, 46, 64-69

Netsell, R., Lotz, W. K., DuChane, A. S. & Barlow, S. M. (1991). Vocal tract aerodynamics during syllable productions: normative data and theoretical implications. Journal of Voice, 5(1), 1-9.

Orlikoff, R. F., & Baken, R. J. (1993). Clinical speech and voice measurement: laboratory exercises. San Diego, CA: Singular Publishing Group, Inc.

Ptacek, P. H., & Sander, E. K. (1963). Maximum duration of phonation. Journal of Speech and Hearing Disorders, 28, 171-182.

Ptacek, P., Sander, E., Maloney, W., & Jackson, C. (1966). Phonatory and related changes with advanced age. Journal of Speech and Hearing Research, 9, 353-360.

Sawashima, M. (1966). Measurement of maximum phonation time, Journal of Japan Society of Phoniatrics, 7, 23-28.

Schutte, H. K. (1981). The efficiency of voice production. Dissertation. University of Groningen.

Schutte, H. K. (1986). Aerodynamics of phonation. Acta Otorhinol Belg, 40, 344-357.

Schutte, H. K. (1992). Integrated aerodynamic measurements. Journal of voice, 6, 127-134.

Seikel, J., King, D., & Drumright, D. (1997). Anatomy and physiology for speech and language. San Diego, CA: Singular Publishing Group, Inc.

Shigemori, Y. (1977). Some tests related to the air usage during phonation. Clinical investigations. Otologia (Fukuoka), 23, 138-166.

Spiegel J. R., Sataloff R. T., Cohn J. R., & Hawkshaw M. (1988). Respiratory dysfunction. In R. T. Sataoff (Ed.), Vocal health and pedagogy (pp.147-159). San Diego, CA: Singular Publishing Group, Inc.

Stathopolous, E. T., & Sapienza, C. (1993). Respiratory and laryngeal function of women and men during vocal intensity variation. Journal of Speech and Hearing Research, 36, 64-75.

Warren, D. W. (1982). Aerodynamics of speech. In N. J. Lass, L. V. McReynolds, J. L. Northern, & D. E. Yoder (Eds.), Speech, language and hearing: Normal process (pp. 219-245). Philadelphia: WB Saunders.

Wilson, J. V., & Leeper, H. A. (1992). Changes in laryngeal airway resistance in young adult men and women as a function of vocal sound pressure level and syllable context. Journal of Vocice, 6, 235-245.